18 CONSTRUCTION SUPPLY CHAIN RESILIENCE

- Building Capabilities and Withstanding Vulnerabilities

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Abstract

Construction industries worldwide have already suffered significantly from COVID-19-related major supply chain disruptions. Construction supply chains are also vulnerable to weaknesses in global supply chains. Therefore, it is timely for construction organisations to revamp their strategies and operating procedures to counteract these vulnerabilities to enhance their own performance and that of the industry. Supply chain resilience (SCR) is taken to be the dynamic capability of supply chains to withstand the influential vulnerabilities in a tumultuous global supply chain environment by developing and deploying appropriate capabilities. Further, SCR envisages a game-changing strategic shift from traditional supply chain risk management practices, to enable effective counteracting of various vulnerabilities: by anticipating, withstanding and overcoming them, while also empowering proactive resilience through appropriate dynamic capabilities. This chapter describes a completed exercise to identify critical vulnerabilities associated with construction supply chains and thereby ascertain the capabilities that should be developed to withstand them. Further, the dynamic balance between capabilities and vulnerabilities, their individual impacts, and the supply chain vulnerability levels in different phases of procurement and delivery, were explored through a specific case study that focused on industrialised construction in Hong Kong, given increasing trends in many countries towards reduced on-site operations, by shifting the production of most building components to factories. Finally, a set of strategies to boost SCR is proposed, based on the case study findings but adaptable to other jurisdictions. Moreover, the findings in this chapter should benefit contractors, clients/employers, policymakers and other industry stakeholders to rethink 'business as usual' and develop innovative strategies and methodologies to reduce supply chain vulnerability levels during all phases of construction project procurement and delivery while identifying and developing relevant counteracting capabilities.

Keywords: Supply Chain Resilience; Supply Chain Vulnerabilities; Supply Chain Disruptions; Supply Chain Capabilities; Construction Supply Chain; Industrialised Construction; Procurement and Delivery

18.1 Introduction: Supply chain resilience - moving beyond conventional risk management

The emergence of the COVID-19 pandemic first alarmed the World then changed ways of living and working and also showed how global supply chains are susceptible to a wide array of unforeseeable and unavoidable disruptions. The pandemic triggered acute supply chain disruptions due to material shortages and unavailability, logistics and transportation issues, factory closure, and unavailability of labour (Cherian and Arun, 2022). Further, country lockdowns and the COVID-19 regulations caused adverse impacts on the global economy while resulting in negative Gross Domestic Product (GDP) in around 170 countries (IMF, 2020; Cherian and Arun, 2022). Supply chains in most industries, including agriculture, automobile, tourism, textile, and building and construction were significantly affected during and after the COVID-19 pandemic.

However, such industrial supply chains face disruptions even during their normal operations in general due to human-induced disasters or Act-of-God situations. All these disruptions more or less endanger organisational performance. Also, the growing complexity of the global supply chains and their increased vulnerability to disruptions have threatened the long-term success and survival of organisations and sometimes their parent industries too (Ekanayake et al., 2021a). Therefore, given the increasing fragility and the susceptibility of global supply chains due to unforeseen disruptions, the highly volatile and interconnected nature of the global market, fierce competition amongst organisations and ever-changing clients' demands necessitates a strategic shift toward a modern supply chain management strategy that prioritises Supply Chain Resilience (SCR) (Ekanayake et al., 2021a; Zavala, et al., 2019). SCR is one of the key clusters that emerged in the 'Resilience' concept. The resilience concept refers to the ability to deal with disruptions. It is said to be an outcome measure with an end goal of resistance, absorption, and recovery to the pre-event state or a steadier state (restoration) (Cutter et al., 2010). Resilience is twofold: proactive (operationalised through warning capabilities) and reactive (the ability of a system to bounce back and return to equilibrium or a better functional state) (Pettit et al., 2013; Brandon-Jones et al., 2014). Further, resilience straddles diverse disciplines and SCR is also one of the emerging clusters explored in the discipline of management and engineering.

SCR denotes the 'adaptive capability of a supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function' (Ponomarov and Holcomb, 2009). Accordingly, resilient supply chains facilitate the continuity of supply chain networks during disruptions in the first instance. Secondly, they provide the capability to make operational changes in the processes to reduce their vulnerability to disturbances (Christopher and Peck, 2004; Sheffi and Rice, 2005; Zavala et al., 2019; Ekanayake et al., 2021a). SCR denotes a proper balance between the associated vulnerabilities and the counteractive capabilities in the supply chains (Pettit et al., 2013; Ekanayake et al., 2021c). Besides, SCR goes beyond the traditional risk management strategies while enabling identifying, monitoring and mitigating supply chain disruptions (Melnyk et al., 2009) and withstanding them swiftly and cost-effectively (Ekanayake et al., 2021d).

Organisations have been adopting various traditional risk management strategies to identify assess, control and manage supply chain disruptions over the years. However, these traditional risk management strategies focus more on risk reduction, avoidance or control and lower-level consideration is on the restoration and recovery of supply chains as a whole. Further, the following are some major shortfalls of traditional risk management that justified the need for a far better mechanism to deal with supply chain vulnerabilities more effectively.

(a) the difficulty of identifying all potential risks to conduct appropriate risk assessments (Van Der Vegt et al., 2015),
(b) the difficulty in applying common risk management strategies to every potential disruptive cause (Pettit et al., 2010),
(c) the inability to facilitate the required protection against disruptions whose root causes are undetectable (Van Der Vegt et al., 2015),
(d) the difficulty of anticipating and predicting the cascading impacts of supply chain disruptions as most of them emerge as a set of joint or sequential events (Van Der Vegt et al., 2015; Zainal and Ingirige, 2018a),
(e) the difficulty of adequately responding to the low-probability, high-impact disruptive events (Pettit et al., 2010),
(f) the requirement of empirical data, mathematical modelling and probability distributions for risks identification and future predictions (Van Der Vegt et al., 2015; Ekanayake et al., 2021a)

Being resilient was a timely solution to better manage the identified weaknesses associated with previous risk management approaches as SCR goes beyond mitigating risk and enables organisations to deal with disruptions more effectively (Fiksel, 2015) by improving withstanding capacity of supply chains through adequately deployed supply chain capabilities. More importantly, the level of vulnerability of supply chains is closely related to the withstanding capacity of supply chains. Supply chain A with stronger withstanding capacity would perform better towards disruptions compared to supply chain B with lesser capacity. Hence, more attention should be paid to strengthening the appropriate supply chain capabilities in the supply chains rather than just identifying, assessing and reactively addressing the risks to withstand disruptions. In this regard, an appropriate balance between vulnerabilities and capabilities should be maintained proactively (Pettit et al., 2019) by considering supply chain dynamics. The employment of an appropriate level of capabilities is clearly vital. It is noted that more capabilities than presently foreseen may be needed to tackle unforeseen levels of potential disasters or even totally unforeseen disasters, i.e., a redundancy or 'buffer back-up' of capabilities should ideally be available to draw on if needed. However, excessive overprovision of redundant resources (human, financial, technological etc.) that may most probably not be needed, would be wasteful and incur additional time and cost with other detrimental impacts. As will be described later, developing capabilities of anticipation and visibility (having proper knowledge of ongoing supply chain operations and its environment) helps to assess the probably required levels of other capabilities so as to make proactive provisions to withstand future disruptions at those levels. Therefore, an additional 'buffer' can be provided in the 'balance' to provide more capabilities than currently seem needed. This would add a 'safer factor' or additional backup provision to cope with totally unforeseeable and unexpectedly prolonged disruptions such as COVID-19. Moreover, the emerging attention of practitioners is now shifted towards building resilient supply chains as a recognised solution to address the difficulties arising from the inadequacy of traditional risk management practices since SCR facilitates organisations with adaptive capabilities that are ideally developed to counteract and withstand corresponding vulnerabilities in supply chains effectively and to enhance recoverability in the presence of a disruption. Figure 18.1 explicates the concept further, illustrating the need for SCR initiation and how it could help in overcoming vulnerabilities to target a goal of high performance.

Insert about here: Figure 18.1: Supply Chain Resilience

18.2 Construction supply chain resilience - imperatives to improve

It is common knowledge that the construction industry is one of the most significant drivers of the global economy as the industry contributes significantly to the built environment and economic growth while generating massive employment opportunities. Compared to developed countries, in developing countries, the proportional contribution of the construction industry is higher, as has been recognised over the years (Ekanayake et al., 2021d). Besides, given the pivotal role played by the industry in the national economy, governments have appointed and empowered industry review/ appraisal committees periodically, to review the performance of their construction industry and to propose strategic reforms to enhance industry performance. For example, some recent developments in the United Kingdom, Singapore and Hong Kong were based on useful recommendations from earlier reports (Egan, 1998; C21, 1999; CIRC, 2001).

However, countries are still looking for innovative solutions that enhance industry performance, since construction projects still suffer from delays, cost overruns, safety problems, and environmental and sustainability issues. Indeed, the construction industry is not exempted from being affected by the interconnected risks associated with global dilemmas. Like most other industries, the construction industry also faces significant supply chain disruptions due to the worldwide crisis and pandemics. During the Japanese triple disaster in 2011 triggered by a tsunami (which led to a nuclear disaster and flooding too) and the European migration crisis in 2015, the global supply chains and industries including construction were greatly affected. Also, SARS in 2003, and most recently, the COVID-19 pandemic have adversely affected the construction industry's performance. Apart from that, the Russian-Ukraine War again resulted in supply chain disruptions over the world. BREXIT is another example that resulted in a skilled worker shortage in the United Kingdom and the recent economic crisis in Sri Lanka depicted how challenging it is for an industry such as construction to survive with resource (material, fuel, labour) shortages during such an economic shortfall.

Delving deeper, the supply chain interdependencies in the construction industry are unique. The construction supply chains are characterised by project-based delivery, overlapping risks (Loosemore, 2000) and more cascading nature of risks. Further, the consequential losses are considerably high in the construction industry as the contractors are obliged to pay a higher amount of liquidated damages caused by delays and significant penalties for performance shortfalls. Indeed, the reliance on 'Trade Credit' is higher in the construction industry (Nowak and Gorczynski, 2020) and hence, is allied with more supply chain risk. Even the contractual responsibilities of the supply chain members are wider and more direct, hence, vulnerabilities trigger faster in the construction industry compared to the other industries (Loosemore, 2000). Considering the configuration of a conventional construction supply chain, the upstream and downstream linkages could be identified as follows. The upstream linkages include the construction client and the design team, leading the projects and the downstream linkages include the main contractor, the suppliers and the sub-contractors, delivering the projects (Ekanayake et al., 2021d). All these supply chain members form the context of temporary multiple organisations and work together to attain their individual interests under a common project goal. Accordingly, the supply chain management process in the construction industry faces numerous significant challenges due to the difficulties of managing a wider network of organisations, suppliers and services (Dainty et al., 2001; Briscoe and Dainty, 2005) with adversarial relationships (Saad et al., 2002).

As a solution to the performance and quality shortfalls in construction projects, 'Construction Industrialisation' (the adoption of prefabricated building components and systems) has been introduced a few decades ago (Gibb, 1999; Lawson et al., 2012). The recent progression of prefabricated construction to Modular integrated Construction (the assembly of volumetric units or models onsite) enabled reduced construction time and labour, improved quality, enhanced safety and productivity, and reduced exposure to external services with greater sustainability compared to the previous construction methods used in the industry (Jiang et al., 2019; Wuni and Shen, 2020; Ekanayake et al., 2021d). However, the inherent limitations of complexity, pre-fixed construction schedules (Zhai and Huang, 2017), the fragmented nature and reduced visibility of prefabricated construction supply chains often lead to disruptions which contribute to significant losses and other adverse effects (Ekanayake et al., 2021d). The associated disruptions are not limited to tolerance issues, machine breakdown, port/customs clearance delays, traffic and handling issues in logistics, and damage to the modular units. If these vulnerabilities are not managed effectively and efficiently, the time and cost savings expected from construction industrialisation would undoubtedly wither away. Given these foregoing essentials, becoming (more) resilient would herald the strategic transformation of the construction industry by improving its readiness to withstand uncertainties and disruptions to enhance industry performance. Moreover, SCR prioritisation could be introduced as a game-changing management strategy for the construction industry that outperforms traditional risk management practices by withstanding critical supply chain disruptions while overcoming so-called vulnerabilities effectively and efficiently. Therefore, the forthcoming sections of this chapter discuss how to improve construction SCR through building capabilities and withstanding vulnerabilities.

18.3 Vulnerabilities in construction supply chains - differentiating from risks and identifying root causes

As discussed above, construction supply chains face acute disruptions not only due to external environmental factors such as those stemming from sudden and serious social, political, and economic issues and 'dislocations' but also due to the strategic and managerial decision-making of construction organisations and project managers. Further, higher complexity, extensive outsourcing, and less vertical integration of supply chains expose organisations to an increased level of vulnerabilities. In previous literature, vulnerabilities were identified and considered as 'risks' (Chopra and Sodhi, 2004), 'disruptions' (Ponomarov and Holcomb, 2009), 'uncertainties', 'errors', and 'crises' (Ekanayake et al., 2020a). However, in SCR, vulnerabilities signify the key disruptions that disturb normal supply chain operations

(Ekanayake et al., 2020a). Indeed, the degree of vulnerability denotes the level of fragility of systems (Elleuch et al., 2016),

18.3.1 Risk vs Vulnerability

There is an identifiable difference between risk and vulnerability. Risk is characterised by the probability (frequency of happening risk) and its impact (the amount of loss) (Elleuch et al., 2016). According to Heckmann et al. (2015), it is 'the fear of losing investment' or 'the probability of events that result in losses. In the domain of supply chain risk management, supply chain risks denote the 'variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective values' (March and Shapira, 1987).

However, vulnerability is measured through the intensity of the impact generated or the damage caused (Elleuch et al., 2016). Hence, vulnerability is characterised by the predisposition to risk, strength-building, and elasticity to withstand shock (Gondard-Delcroix and Rousseau, 2004). Further, it denotes the degree of fragility of systems (Bonnefous et al., 1997). Indeed, vulnerability depends upon a system's capacity and preparation to anticipate, face, and absorb risks (Birkmann, 2007). Risk can be therefore measured by the function of the hazard and vulnerability (Wisner et al., 2004; Ekanayake et al., 2020a).

For instance, vulnerability levels of building A and building B to natural disasters can differ although they are in the same risk area. Because building A may be more vulnerable to natural disasters due to less careful design and construction. But building B could be properly designed, constructed, and well maintained and therefore, building B could be less vulnerable to natural disasters. Similarly, construction supply chain X may be more vulnerable than construction supply chain Y to transportation disruptions. The reason would be that supply chain Y would be more adaptive and with enhanced coping capacities to withstand most transportation disruptions. Indeed, supply chain Y would have alternative transportation arrangements to properly reroute whenever required during disruptions. As a result, supply chain X will incur more losses and costs compared to supply chain Y when facing disruptive causes. Moreover, vulnerability is associated with system or supply chain capacity which enables effective withstanding of disruptions and bouncing back from them. Besides, supply chains can be differently vulnerable to the same risk events given their supply chain capabilities (Ekanayake et al., 2020b).

18.3.2 Vulnerabilities in Construction Supply Chains

As identified in the literature, most construction supply chains face a wide array of disruptions stemming from strategic management as well as from other issues, such as personal, process, supplier/customer, technology, political/legal/economic, environmental, physical damage, market pressures, and liquidity or credit vulnerabilities (Zainal and Ingirige, 2018b). Especially for prefabricated/industrialised construction supply chains, the key disruptions are from project organisational, procedural, technological, supplier/customer, external environmental, and financial vulnerabilities (Ekanayake et al., 2020a).

Organisational and project vulnerabilities arise due to poor strategic and management decisions and the actions taken by the staff and employees within construction organisations and projects. These vulnerabilities include labour strikes and labour disputes; loss of skilled workforce; disruptions due to outsourcing, communication breakdowns; loss of trust/fraud; closing/selling off the organisations; and poor project definition. Procedural vulnerabilities can be considered process-based disruptions and arise from the operation at any node of the supply-production-distribution chain (Ekanayake et al., 2020a). The procedural vulnerabilities include variations/rework; utility breakdowns; transport disruptions; quality loss; systems/machines breakdown; site inventory losses/theft; safety hazards; and energy scarcity (Ekanayake et al., 2020a). Technological vulnerabilities are also significant in the construction industry as they include the disruptions resulting from technology changes and breakdowns. Accordingly, technology failure, information loss and misuse, IT system failure and failures due to outdated IT systems (Ekanayake et al., 2020b) could be faced. Supplier/customer vulnerabilities refer to the disruptions allied with suppliers, sub-contractors, contractors and the client in the supply chain. These vulnerabilities begin with supply resource scarcity or shortages (Zhai and Huang, 2017) and progress with the supply-demand mismatch (Ekanayake et al., 2020a) and end up with unmet client needs (Hou et al., 2018). Further, construction supply chains, in particular, depend upon a single contractor as it is not feasible to arrange backup contracts within a single project. Therefore, single supplier dependency is another challenging vulnerability that the industry faces.

In addition, external environmental vulnerabilities can arise from Act-of-God natural disasters or human-induced disasters. As realised throughout the previous years, the COVID-19 pandemic, economic crisis, natural disasters and war situations imposed acute susceptibilities on the construction industry in general and supply chain delays and disruptions in particular. The financial capacity of construction organisations should be much stronger than in other industries as the industry deals with such an expensive and risky product delivery. Most of the vulnerabilities in the industry arise due to liquidity or credit issues relating to money and poor management of monetary assets and insolvency (Ekanayake et al., 2020a). Further, construction supply chains are susceptible to cost overrun, cash flow issues, price and exchange rate fluctuations, inflation, and liability claims. Accordingly, there can be a detrimental impact of late payment to the suppliers, sub-contractors and even to the contractor which will cause a loss of trust in the project team (Kadir et al., 2005). Despite the good financial strength, it is difficult to expect excellent or good performance or even survival of the construction supply chains. Therefore, maintaining a healthy cash flow and strong financial capacity is essential to properly address the financial risks associated with the construction supply chains.

Within these vulnerability categories, the most critical vulnerability factors of construction supply chains include political or regulatory changes, market pressures and vulnerabilities due to management, and strategic and financial decision-making (Zainal and Ingirige, 2018b). However, the above identification is based on Malaysian construction projects. Further to the findings, public construction projects are highly vulnerable to political threats whereas private sector organisations are significantly vulnerable to market pressures. In addition, the public sector's financial strength is also challenging and hence, creates significant vulnerabilities during the supply chain process. Especially considering the prefabricated construction supply chains in China, the most critical vulnerabilities are due to high cost, an inadequate workforce, inadequate training and policy-related issues (Wang et al., 2019). As prefabricated construction is still growing, the developed policies on it do not still cover the overall aspects. Indeed, the initial cost implication is significantly higher in prefabricated construction and having a proper financial capacity is essential in this regard. Further, manufacturing, transportation, handling and assembly of prefabricated modules require a skilled and trained workforce. Finding such a skilled and trained workforce is not easy and may therefore generate vulnerabilities due to labour inefficiency and safety issues.

A loss of skilled workforce is the highest vulnerability faced by the Hong Kong prefabricated construction supply chains (Ekanayake et al., 2021d). Especially, on-site assembly is impossible without skilled labour. Hence, the workforce should be extensively trained, while several mock-up sessions should be conducted to avoid safety hazards and tolerance issues during the actual installation of the prefabricated components. Further, dealing with variations is another considerable vulnerability as the prefabricated supply chains are fixed after the planning stage. For instance, even a 2-3 mm error in some prefabricated modules/component dimensions would create significant assembly issues that may generate significant cost overruns in the projects. Also, communication issues are much more challenging and unavoidable in the prefabricated construction supply chains in Hong Kong due to the fragmented nature of the supply chains. For example, the prefabricated units are manufactured in Mainland China and transported to Hong Kong for assembly. Therefore, a proper communication mechanism is essential for quality management and control, logistics management, inventory management and on-site assembly management including appropriate scheduling.

Besides, all these supply chain vulnerabilities are independent of each other but impose cascading impacts on the others. Therefore, they can arise together, in parallel or in sequence. For instance, technological vulnerabilities may tend to trigger financial vulnerabilities and the cumulative vulnerability level of combined vulnerabilities could affect the whole construction supply chain in different ways. Moreover, all these supply chain vulnerabilities are product-specific and jurisdiction-specific, hence, it is necessary to identify and link them specifically to their own industries and jurisdictions when developing resilient supply chains. Therefore, developing and deploying appropriate supply chain capabilities at appropriate levels is necessary, to benefit from adequate SCR throughout project procurement and delivery cycles. The benefits would indeed be enhanced and multiplied in longer-term supply chains that serve more than single one-off projects but extend to project programmes such as for public housing clients or private developers, with ensuing synergies in overlapping project procurement and delivery. The overlaps could be both (a) 'horizontally' as in overlapping projects that proceed almost in parallel but start and finish at slightly different times i.e., 'staggered'; and (b) 'longitudinally' as with longer-term programmes of large clients/employers.

18.4 Supply Chain Capabilities - as Drivers for construction firms' Success

The only precursor to SCR is deploying adequate capabilities at appropriate levels in the supply chains. These capabilities contribute toward supply chain strategy and enhance operational excellence while encouraging healthy client relationships (Morash, 2001). Supply chain capabilities act as 'counter-balancers' during disruptions to counteract supply chain vulnerabilities effectively (Pettit et al., 2013). In that sense, supply chain capabilities can anticipate, withstand and overcome supply chain vulnerabilities which disrupt the normal construction supply chain process (Ekanayake et al., 2019). Supply chain capabilities are twofold: proactive and reactive (Wieland and Wallenburg, 2013). The proactive capabilities strengthen the supply chains with the ability to prepare for and withstand supply chain disruptions in more effective ways. The reactive capabilities are activated by the disruptions and enable quick responses to rapid changes while facilitating fast recovery. There are several findings on supply chain capabilities and supply chain capability measures. Supply chain capabilities include but are not limited to visibility, dual sourcing, transshipping (Christopher and Peck, 2004), leanness, agility (Purvis et al., 2016), and flexibility (Tomlin, 2006; Purvis et al., 2016). Each capability could be assessed and improved with the use of supply chain capability measures. For instance, improving the use of tracking and tracing tools is helpful to enhance supply chain visibility. In this regard, the visibility capability in a supply chain can also be assessed by the use of suitable tracking and tracing tools in the supply chain process. In most construction supply chains, Flexibility, Capacity, Efficiency, Visibility, Adaptability, Anticipation, Recovery, Dispersion, Collaboration, Market Position, Security and Financial Strength are the critical capabilities that enable effective withstanding of vulnerabilities (Zainal and Ingirige, 2018b).

Flexible supply chains have the ability for the quick mobilisation of resources during a disruption. The use of multiple sources of supply, multiple uses of resources, and flexible supplier contracts are encouraged to improve flexibility. Having alternative suppliers is also beneficial in this regard but maintaining alternative or backup contracts is impracticable in construction projects. Integrating inventory management and supply chain management through integrated project management support platforms such as BIM (Building Information Modelling) and ERP (Enterprise Resource Planning) helps to improve the flexibility of the supply chain process further. Having alternative/multi-modal transportation is necessitated during logistics disruptions as delays may contribute to significant monetary losses. Maintaining adequate time buffers in the construction schedule is also essential to improve supply chain flexibility.

Capacity is another critical capability measure, as it ensures the availability of sufficient resources to enable continuous supply chain operation. Having proper redundancies in the supply chain process is required for prompt recovery during disruptions without disturbing other supply chain processes. Maintaining safety stocks, backup facilities, inventory buffers and reserves are essential to hedge against uncertainties. Improving the supply chain capacity, therefore facilitates mitigating rearrangement costs and the tardiness penalty (Zhai et al., 2018).

Efficiency is the supply chain's ability to perform higher with reduced use of resources (Ekanayake et al., 2021b). Efficient construction supply chains are encouraged through wastage reduction, reusability, recyclability, initiation of circular economy concepts, improved labour productivity, failure prevention and reduced product variability. Industrialised construction including increasingly popular modular construction approaches enables product variability reduction to a certain extent in construction projects. However, Birkinshaw (2020) argues that efficiency should be replaced by reliability as a supply chain capability to improve resilience aspects in global supply chains. It is suggested to employ multiple suppliers in the supply chain process while matching the local demand with local supply further to improve resilience (Birkinshaw, 2020). Indeed, having additional resources and buffers tends to improve efficiency but reduces the supply chain interdependency (Reeves and Varadarajan, 2020). Retaining alternative or multiple supply sources within a single construction contract is not easy and it incurs much cost (Ekanayake et al., 2021c). Further, maintaining equipment buffers such as tower cranes is a waste and backup maintenance agreements are suggested to receive the expected advantage. Accordingly, the reliability (through backup) measures incur extra costs, hence, reducing 'efficiencies' on paper. This may be a useful price to pay for useful redundancies that increase resilience, which is also seen as more important after COVID-19 (Ekanayake et al., 2021b). Indeed, matching supply or demand on a local basis is even more challenging, especially in the recent developments in industrialised construction. Industrialised construction supply chains are mostly fragmented and vertically integrated. Hence, '100% efficiency' is impracticable and considered to be unnecessary to achieve resilience targets in the construction supply chains (Ekanayake et al., 2021b).

Visibility of the supply chain process should be improved to derive proper knowledge of the current status and resource utilisation in construction supply chains. Business intelligence gathering, deployment of tracking and tracing tools, and real-time data management and information sharing facilitate promising visibility to the supply chains. Adaptability as a supply chain capability provides the ability to modify operations in response to disruptions (Ekanayake et al. 2020c). Employing fast rerouting of requirements (Peck, 2005), conducting parallel processes rather than a series of processes, reducing the lead time in scheduling, conducting virtual simulations before the actual construction, and the use of advanced technology improves supply chain adaptability.

Anticipation which is the ability to recognise and predict future disruptive events is essential to enhance the preparedness of supply chains. Deploying technology-based tools such as RFID, BIM, and GIS improves the early detection of disruptive events and provides warning signals to ensure the continuous operation of supply chains by withstanding the disruptive causes to a large extent, at least. Recovery as a supply chain capability denotes the ability of supply chains to promptly return to the normal operational state or a better state during disruptions. Proper crisis management, consequence mitigation and communication strategy are essential to an effective recovery during a disruption. In addition, decentralisation of resources, and distributed decision-making at construction sites facilitate dispersion capability to uptake SCR.

Working effectively with the other construction professionals, project team and parties for mutual benefits, so-called collaboration is a precursor to SCR. The 'internet of things' enabled BIM works as a collaborative platform to improve construction project delivery. On the other hand, public-private partnerships in projects are useful for sharing disruption risks effectively. Maintaining a good market position with healthy client relationships is essential not only to be resilient but also for the long-term survival of construction firms. Having a good market position and healthy client relationships helps with positive negotiation with the clients and achieving flexibility in supply chain operations during disruptions. Importantly, these capability measures are required to withstand market pressure, economic vulnerabilities and market competition successfully.

Security is the ability of supply chains to deal with deliberate intrusions (Zainal and Ingirige, 2018b; Ekanayake et al., 2021b). Ensuring a secure construction process, adequate personal security, site safety and data security are vital to improving SCR in this regard. Having financial strength is very important to withstand disruptions by enhancing the absorption capacity of supply chains. Maintaining a healthy cash flow, maintaining financial reserves for backup funding, taking all the necessary insurance policies, and implementing strategic partnerships and portfolio diversification are the imperatives to ensure the financial strength and resilience of construction organisations.

Among the aforementioned capabilities, capacity, visibility, anticipation, dispersion, collaboration, market position, security and financial strength support the implementation of proactive resilience capabilities whereas efficiency, adaptability, and recovery are required in reactive capability development. More specifically, a study by Ekanayake et al. (2020b) proposed a specific set of capabilities for achieving SCR in line with the recent developments of industrialised construction such as resourcefulness, flexibility, capacity, adaptability, efficiency, financial strength, visibility, anticipation and dispersion. As a newly added item to the previous list of capabilities, resourcefulness enables a collaborative, secure and resourceful approach to enhance resilience. All these identified supply chain capabilities could be focused upon, for improving practice and influencing different stages of supply chain processes.

Besides, the deployment of these capabilities at adequate levels is essential to avoid the unnecessary waste of resources. For instance, if construction organisations target improved supply chain capacity and deploy additional tower cranes on-site (just for backup during other tower crane breakdowns), it would be expensive and negatively affect the project cash flow and also profits, if not needed. Similarly, enhancing the disaster precautionary measures to a greater extent than legally or even normally required, would lead to excess cash outflows of the projects. However, facilitating some safeguards that may moderately exceed what may be justified by the exact vulnerability-capability balance, seems also needed to provide an additional buffer to cope with totally unforeseeable disruptions such as COVID-19. Therefore, it is crucial to identify the appropriate capabilities, especially the critical supply chain capabilities and to know their relative levels of importance in the supply chains.

18.5 Deploying apposite Capabilities and withstanding Vulnerabilities: an Industrialised Construction Case Study in Hong Kong

Although the previous sections discussed separately the supply chain vulnerabilities and capabilities, SCR can only be attained by maintaining a proper balance between them. Given that, it is essential to understand the co-relational impact of supply chain vulnerabilities and capabilities. In this respect, a supply chain vulnerability-capability analysis model was proposed by Ekanayake, et al. (2021d). The model was based on a detailed study that mainly focused on the industrialised construction sector considering the recent strong initiatives for off-site and modular construction in the Hong Kong construction industry. Accordingly, the findings are mostly specific to Hong Kong's industrialised construction practices as supply chain dynamics are jurisdiction-specific. However, the study facilitates significant research outcomes and directions to think forward to achieve resilient supply chains in the construction industry. Figure 18.2 visualises the supply chain vulnerability-capability co-relationship in industrialised construction projects in Hong Kong. Resourcefulness, Capacity, Flexibility and Dispersion are highlighted in this Figure 18.2 because according to the study findings, these are the critical capabilities that facilitate adequate protection over the critical vulnerability groups, namely: Production-based, Organizational, Procedural and Economic.

Further to the findings of Ekanayake et al. (2021d), production-based vulnerabilities trigger the most critical disruptions that need greater industry attention. For example, 'loss of quality' including tolerance breaches (especially in off-site components), 'labour disputes, and 'supply-demand mismatch/shortages' are associated with production-based vulnerabilities. As above, tolerance breaches could be quite significant in the industrialised construction process. Unless an appropriate/specified tolerance is ensured in the factory, quality issues could create acute disruptions in the assembly process. To withstand these production-based vulnerabilities, resourcefulness capability development is required (Ekanayake et al., 2021d). Capacity as a supply chain capability is also effective in withstanding production-based vulnerabilities.

Insert about here: Figure 18.2: Supply Chain Vulnerability-Capability Co-relationship in Industrialised Construction Projects

Developed from: Ekanayake et al. (2021c)

In addition, improvement of resourcefulness capability helps to withstand economic, organisational and procedural supply chain vulnerabilities. Organisational vulnerabilities are mainly due to outsourcing, communication issues, loss of skilled workforce and inadequate supplier selection. Procedural vulnerabilities could emerge from new laws and regulations, safety issues, transportation disruptions, system/machine breakdowns, and physical damage to components from accidents. Economic vulnerabilities could arise from price and currency fluctuations, economic policy changes, and industry/market pressures to name a few. In this respect, dispersion and flexibility are other important capabilities that enable adequate withstanding of economic supply chain vulnerabilities. The lowest criticality level was received by the technological vulnerabilities as these vulnerabilities are better managed in the current Hong Kong construction practices with already deployed supply chain capabilities. Therefore, there was not any critical vulnerability-capability co-relationship found in this case study to withstand technological vulnerabilities.

Besides, the manufacturing phase and the on-site assembly phases are highly vulnerable phases (Figure 18.3) in industrialised construction supply chains. Moreover, they are highly susceptible to labour-related issues, which are very significant in project procurement and delivery (Ekanayake et al., 2021c). The logistics phase is also marginally vulnerable in terms of supply chain disruptions and faces identical vulnerabilities such as transportation disruptions due to port stoppages or border-crossing delays as may happen when factories are across a border, as in Hong Kong practice.

Insert about here: Figure 18.3: Achieving Supply Chain Resilience in Industrialised Construction in Hong Kong

Developed from: Ekanayake et al. (2021b)

Taken as separate supply chain capabilities, anticipation can make the highest impact on resilience implementation (Figure 18.3) as it provides a greater ability to detect potential supply chain disruptions in advance. Hence, there should be adequate provisions for the deployment of tracking and tracing tools, quality control and intensive training. The least contribution towards achieving SCR is expected from dispersion capabilities (Figure 18.3) as Hong Kong construction practices always encourage dispersion with distributed decision-making in construction projects. Unsurprisingly, the industry was recently suffering from numerous acute supply chain disruptions (post-COVID-19), hence the need for improving capability measures to enhance SCR has emerged, as described before (Ekanayake et al., 2021d).

Development of a smart and interoperable software package (ideally integrating with BIM and GIS, and using Digital Twins and Blockchain) to enable higher data visibility and anticipation, extensive use of modular construction with appropriate technology such as suitable computer-aided and automated manufacturing and labour robots, maintaining in-house prefabrication yards by the construction organisations, and strong policy support are considered vital, hence essential to accelerate SCR in the Hong Kong construction industry. Moreover, SCR is well-thought-out to be a timely and important imperative for developing policy and strategic objectives and protocols to boost supply chain performance in Hong Kong, and other jurisdictions where construction industries now face acute challenges due to unforeseen and unprecedented disruptions that have significantly aggravated existing performance shortfalls.

18.6 Conclusions and Way Forward

The COVID-19 pandemic and the Russian-Ukraine War triggered the most recent substantial global supply chain disruptions at the time of writing this Chapter. They have adversely affected overall construction industry performance while highlighting the need for a far better supply chain management paradigm. In this regard, Supply Chain Resilience could be introduced as a game-changing managerial approach that enables a paradigm shift. Resilient supply chains are fostered with dynamic capabilities to withstand the influential supply chain vulnerabilities in a tumultuous global supply chain environment by developing and deploying appropriate supply chain capabilities.

Given this background, this chapter attempted to bring forward several imperatives associated with construction supply chain resilience. Beginning with identifying the critical vulnerabilities and their counteracting capabilities in construction supply chains, the chapter then proceeded to describe the concept of balanced resilience. Moreover, facilitating adequate safeguards with the use of safety buffers without sticking to the exact vulnerability-capability balance is shown to be needed to cope with totally unforeseeable disruptions such as COVID-19. Thereafter, findings from a Hong Kong industrialised construction case study were presented in this chapter to provide an idea about how to achieve a dynamic balance between capabilities and vulnerabilities, their individual impact, and the vulnerability levels of supply chains in different phases of procurement and delivery.

Also, the set of strategies proposed to boost SCR (in the last section of this chapter) is beneficial in realising the expected performance objectives of industrial construction projects. Although SCR is jurisdiction-specific and the findings presented are linked with the Hong Kong construction practices, many other jurisdictions where construction industries now face acute challenges should also be able to adopt and adapt these initiatives to suit their own contexts, needs and priorities in developing policy goals, strategic management objectives and action plans. Moreover, these SCR initiatives are significantly beneficial to contractors, clients/employers, policymakers and other industry stakeholders to rethink, revise and reshape their strategies and methodologies to reduce the vulnerability levels of supply chains during construction project procurement and delivery with the ultimate aim of achieving heightened performance in the construction industry.

18.7 References

Birkinshaw, J. M. (2020) 'The new boadroom imperative: from agility to resilience', *Forbes,* 28, p. 2020.

Birkmann, J. (2007) 'Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications', *Environmental hazards*, 7(1), pp. 20–31.

Bonnefous, S., Massuelle, M. H. and Richard, V. (1997) '*Aspects sémantiques du risque', Vocabulaire lié au risque à travers une analyse bibliographique*: IPSN.

Brandon-Jones, E., Squire, B., Autry, C. W. and Petersen, K. J. (2014) 'A Contingent Resource-Based Perspective of Supply Chain Resilience and Robustness', *Journal of Supply Chain Management*, 50(3), pp. 55–73. doi: 10.1111/jscm.12050.

Briscoe, G. and Dainty, A. (2005) 'Construction supply chain integration: an elusive goal?', *Supply chain management: an international journal*, 10(4), pp. 319–326.

C21 (1999) *Reinventing Construction*, Construction 21 Review Committee, Ministry of Manpower and Ministry of National Development, Sigapore.

Cherian, T. M. and Arun, C. J. (2022) 'COVID-19 impact in supply chain performance: a study on the construction industry', *International Journal of Productivity and Performance Management*, (ahead-of-print). https://doi.org/10.1108/IJPPM-04-2021-0220.

Chopra, S. and Sodhi, M. S. (2004) 'Supply-chain breakdown', *MIT Sloan management review*, 46(1), pp. 53–61.

Christopher, M. and Peck, H. (2004) 'Building the resilient supply chain.', *International Journal of Logistics Management*, 15(2), pp. 1–13.

CIRC (2001) *Construct for Excellence*. Construction Industry Review Committee (CIRC), HKSAR Government, Hong Kong.

Colicchia, C., Dallari, F. and Melacini, M. (2010) 'Increasing supply chain resilience in a global sourcing context', *Production Planning and Control*, 21(7), pp. 680–694. doi: 10.1080/09537280903551969.

Cutter, S. L., Burton, C. G. and Emrich, C. T. (2010) ‘Disaster resilience indicators for benchmarking baseline conditions’, *Journal of homeland security and emergency management*, 7(1), p. Article 51.

Dainty, A. R. J., Millett, S. J. and Briscoe, G. H. (2001) ‘New perspectives on construction supply chain integration’, *Supply chain management: An international journal*, 6(4), pp. 163–173.

Egan, J. (1998) *Rethinking construction: the report of the Construction Task Force to the Deputy Prime Minister*, John Prescott, on the scope for improving the quality and efficiency of UK construction.

Ekanayake, E. M. A. C., Shen, G. Q. and Kumaraswamy, M. (2021a) ‘Supply chain resilience: mapping the knowledge domains through a bibliometric approach’, *Built Environment Project and Asset Management*, 11(4), pp. 705–721.

Ekanayake, E.M.A.C., Shen, G. Q. and Kumaraswamy, M. M. (2021b) ‘Identifying supply chain capabilities of construction firms in industrialized construction’, *Production Planning and Control*, 32(4), pp. 303–321. doi: 10.1080/09537287.2020.1732494.

Ekanayake, E.M.A.C., Shen, G.Q., Kumaraswamy, M.M., Owusu, E.K. and Xue, J. (2021c) Capabilities to Withstand Vulnerabilities and Boost Resilience in Industrialized Construction Supply Chains: A Hong Kong Study. *Engineering, Construction and Architectural Management*. 29(10), 3809-3829. DOI: 10.1108/ECAM-05-2021-0399.

Ekanayake, E.M.A.C., Shen, G.Q., Kumaraswamy, M.M., Owusu, E.K. and Abdullahi, S. (2021d) Modelling Supply Chain Resilience in Industrialized Construction: A Hong Kong Case. *Journal of Construction Engineering and Management*. 147(11). 05021009-1-16, 10.1061/(ASCE)CO.1943-7862.0002188.

Ekanayake, E.M.A.C., Shen, G.Q., Kumaraswamy, M.M. and Owusu, E.K. (2020a) Identifying supply chain vulnerabilities in industrialized construction: an overview. *International Journal of Construction Management*, 22(8), pp.1464-1477. DOI:10.1080/15623599.2020.1728487.

Ekanayake, E.M.A.C., Shen, G.Q., Kumaraswamy, M.M. and Owusu, E.K. (2020b) Critical Supply Chain Vulnerabilities Affecting Supply Chain Resilience in Industrialized Construction in Hong Kong. *Engineering, Construction and Architectural Management*. 28(10), 3041-3059. DOI 10.1108/ECAM-06-2020-0438.

Ekanayake, E. M. A. C., Shen, G. and Kumaraswamy, M. M. (2020c) ‘Critical capabilities of improving supply chain resilience in industrialized construction in Hong Kong’, *Engineering, Construction and Architectural Management*. 28(10), 3236-3260. DOI 10.1108/ECAM-05-2020-0295.

Ekanayake, E. M. A. C., Shen, G. Q. P. and Kumaraswamy, M. (2019) Managing Vulnerabilities and Capabilities for Supply Chain Resilience in Industrialized Construction. In Proceedings of the *ARCOM2019* Conference. 02-04 September 2019 at Leeds Beckett University, Leeds, United Kingdom. pp.811-820.

Elleuch, H., Dafaoui, E., Elmhamedi, A. and Chabchoub, H. (2016) ‘Resilience and Vulnerability in Supply Chain: Literature review’, *IFAC-PapersOnLine*, 49(12), pp. 1448–1453. doi: 10.1016/j.ifacol.2016.07.775.

Fiksel, J. (2015) ‘*From risk to resilience*’, in Resilient by design. Springer, pp. 19–34.

Gibb, A. G. F. (1999) *Off-site fabrication: prefabrication, pre-assembly and modularisation*. John Wiley & Sons.

Gondard-Delcroix, C. and Rousseau, S. (2004) Vulnerability and Sustainable Risk Management Strategies: A Study Applied to Rural Households in Madagascar. *The human and social dimensions of Sustainable Development*. File 3 (2004), doi: 10.4000/developpementdurable.1185.

Heckmann, I., Comes, T. and Nickel, S. (2015) ‘A critical review on supply chain risk–Definition, measure and modeling’, *Omega*, 52, pp. 119–132.

Hou, Y., Wang, X., Wu, Y.J. and He, P. (2018) ‘How does the trust affect the topology of supply chain network and its resilience? An agent-based approach’, *Transportation Research Part E: Logistics and Transportation Review*, 116, pp. 229–241. doi: 10.1016/j.tre.2018.07.001.

IMF (2020), *Policy Responses to Covid-19*, International Monetary Fund, Washington, District of Columbia, available at:https://www.imf.org/en/Topics/imf-and-covid19/Policy-Responses-to-COVID-19#I (accessed 23 Jan 2021).

Jiang, Y., Zhao, D., Wang, D. and Xing, Y. (2019) ‘Sustainable performance of buildings through modular prefabrication in the construction phase: A comparative study’, *Sustainability*, 11(20). doi: 10.3390/su11205658.

Kadir, M. R. A., Lee, W. P., Jaafar, M. S., Sapuan, S. M. and Ali, A. A. A. (2005) ‘Factors affecting construction labour productivity for Malaysian residential projects’, *Structural survey*, 23(1), pp. 42–54.

Lawson, R. M., Ogden, R. G. and Bergin, R. (2012) ‘Application of Modular Construction in High-Rise Buildings’, *Journal of Architectural Engineering*, 18(2), pp. 148–154. doi: 10.1061/(ASCE)AE.1943-5568.0000057.

Loosemore, M. (2000) *Crisis management in construction projects*. Reston, VA: American Society of Civil Engineers.

March, J. G. and Shapira, Z. (1987) ‘Managerial perspectives on risk and risk taking’, *Management science*, 33(11), pp. 1404–1418.

Melnyk, S.A., Rodrigues, A. and Ragatz, G.L. (2009) *Using simulation to investigate supply chain disruptions. In Supply Chain Risk* (pp. 103-122). Springer, Boston, MA.

Morash, E. A. (2001) ‘Supply chain strategies, capabilities, and performance’, *Transportation journal*, 41(1), pp. 37–54.

Nowak, D. and Gorczynski, S. (2020) ‘A qualitative approach to trade credit in business organisations’. Accessible at http://hdl.handle.net/10610/4235.

Peck, H. (2005) ‘Drivers of supply chain vulnerability: An integrated framework’, *International Journal of Physical Distribution and Logistics Management*, 35(4), pp. 210–232. doi: 10.1108/09600030510599904.

Pettit, T. J., Croxton, K. L. and Fiksel, J. (2013) ‘Ensuring supply chain resilience: Development and implementation of an assessment tool’, *Journal of Business Logistics*, 34(1), pp. 46–76. doi: 10.1111/jbl.12009.

Pettit, T. J., Croxton, K. L. and Fiksel, J. (2019) ‘The evolution of resilience in supply chain management: a retrospective on ensuring supply chain resilience’, *Journal of Business Logistics*, 40(1), pp. 56–65.

Pettit, T. J., Fiksel, J. and Croxton, K. L. (2010) ‘Ensuring supply chain resilience: development of a conceptual framework’, *Journal of business logistics*, 31(1), pp. 1–21.

Ponomarov, S. Y. and Holcomb, M. C. (2009) ‘Understanding the concept of supply chain resilience’, *The International Journal of Logistics Management*, 20(1), pp. 124–143. doi: 10.1108/09574090910954873.

Purvis, L., Spall, S., Naim, M. and Spiegler, V. (2016) ‘Developing a resilient supply chain strategy during “boom” and “bust”’, *Production Planning and Control*, 27(7–8), pp. 579–590. doi: 10.1080/09537287.2016.1165306.

Reeves, M. and Varadarajan, R. (2020) ‘*When Resilience is More Important than Efficiency*’, BCG/Henderson Institute, Boston.

Saad, M., Jones, M. and James, P. (2002) ‘A review of the progress towards the adoption of supply chain management (SCM) relationships in construction’, *European Journal of Purchasing & Supply Management*, 8(3), pp. 173–183.

Sheffi, Y. and Rice, J. B. J. (2005) 'A supply chain view of the resilient enterprise', *MIT Sloan management review*, 47(1), pp. 41–48.
Tomlin, B. (2006) 'On the value of mitigation and contingency strategies for managing supply chain disruption risks', *Management Science*, 52(5), pp. 639–657. doi: 10.1287/mnsc.1060.0515.
Van Der Vegt, G. S., Essens, P., Wahlström, M. and George, G. (2015) '*Managing risk and resilience*'. Academy of Management Briarcliff Manor, NY.
Wang, Z. L., Shen, H. C., Zuo, J., Shen, H. C. and Zuo, J. (2019) 'Risks in Prefabricated Buildings in China: Importance-Performance Analysis Approach', *Sustainability*, 11(12), pp. 3450:1–13. DOI: 10.3390/su11123450.
Wieland, A. and Wallenburg, C. M. (2013) 'The influence of relational competencies on supply chain resilience: A relational view', *International Journal of Physical Distribution and Logistics Management*, 43(4), pp. 300–320. DOI: 10.1108/IJPDLM-08-2012-0243.
Wisner, B., Blaikie, P. M., Blaikie, P., Cannon, T. and Davis, I. (2004) *At risk: natural hazards, people's vulnerability and disasters*. Psychology Press.
Wuni, I. Y. and Shen, G. Q. (2020) 'Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies', *Journal of Cleaner Production*, 249, p. 119347. DOI: 10.1016/j.jclepro.2019.119347.
Zainal, N. A. and Ingirige, B. (2018a) 'Identification of the "pathogenic" Effects of Disruptions to Supply Chain Resilience in Construction', *Procedia Engineering*, pp. 467–474. DOI: 10.1016/j.proeng.2018.01.060.
Zainal, N. A. and Ingirige, B. (2018b) 'The dynamics of vulnerabilities and capabilities in improving resilience within Malaysian construction supply chain', *Construction Innovation*, 18(4), pp. 412–432. DOI: 10.1108/CI-09-2017-0079.
Zavala, A., Nowicki, D. and Ramirez-Marquez, J. E. (2019) 'Quantitative metrics to analyze supply chain resilience and associated costs', Proceedings of the Institution of Mechanical Engineers, *Part O: Journal of Risk and Reliability*, 233(2), pp. 186–199. DOI: 10.1177/1748006X18766738.
Zhai, Y. and Huang, G. Q. (2017) 'Operational Hedging and Coordination in Prefabrication Construction Industry', *Procedia Manufacturing*, 11, pp. 1178–1183. DOI: 10.1016/j.promfg.2017.07.242.
Zhai, Y., Zhong, R. Y. and Huang, G. Q. (2018) 'Buffer space hedging and coordination in prefabricated construction supply chain management', *International Journal of Production Economics*, 200, pp. 192–206.